A METHOD FOR REDUCTION OF AXIAL POWER VARIATIONS OF A WIND POWER PLANT

This invention relates to a method for adjusting the angle of the rotor blades about their own longitudinal axis in a wind power plant in such manner that the thrust of the rotor on the tower is controlled and kept within desired values without the average output of the wind power plant being affected to any noticeable degree. This has the advantage that the load variations on the rotor blade and tower are reduced, thereby substantially reducing fatigue of these heavily loaded components.

In this patent application the following definitions are used:
1) Momentary wind velocity is defined as the momentary wind velocity that is measured at a particular point in time.
2) Average or levelled wind velocity is defined as the average or approximately the average of the momentary wind velocity for a certain period. This period will typically be longer than three seconds and normally in the range of 10 minutes to one hour, but it can also be longer. When the wind velocity is used to control the wind turbine, scaling or fractions of such measured values will also be covered by this definition.
3) Pitch angle in this patent application is defined as the rigid body torsion of a rotor blade about its own longitudinal axis relative to a fixed starting position for this angle. By pitching the blades, the forces on the rotor for a given momentary wind velocity can be varied.
4) Rotor axial force is defined as the thrust that is transferred from the rotor towards the mill housing and which is directed essentially along the rotational axis of the rotor axis. This force consists of the total thrust in the wind direction from the rotor blades and may be both positive and negative at different times during the operation of the wind power plant.
5) Nominal wind velocity is defined as the wind velocity at which the wind power plant first achieves full output. This may typically be in the range of 12-14 m/s.
6) Converter unit is the unit which generates or converts energy from the wind/rotation of the rotor blades into electric power or other mechanical power. This unit may typically be a generator, a mechanical pump, a gear unit or the like. In the following description the term "generator" is used for the most part, but it is clear that generator can be replaced by any type of suitable converter unit as mentioned here.

It is desirable to be able to place large commercial horizontally shafted wind turbines on foundations in deep water. This is desirable in order to be able to increase potential regions for wind power exploitation, to obtain access to areas with high average wind velocities and to be able to build wind parks in proximity to oil and gas installations so as to be able to provide these with electricity using wind power.

In deep water, a floating structure will be advantageous in order to limit the size and costs of towers and foundations.

A floating structure of this kind will primarily be affected by two types of forces that will control the motion pattern and stresses on the floating structure. These are waves forces against the floating part of the structure and thrust on the rotor from the wind, referred to herein as the rotor axial force.

For a wind power plant on land or in shallow water that is fixed to the ground or seabed, the dominant forces acting on the structure will usually be, in addition to gravitational forces, the thrust on the rotor from the wind.

For large wind power plants (with outputs of typically 1 MW or more) there are today two main types of regulating mechanisms used to control that the rotor provides a constant output power, equal to the nominal output of the plant, for wind velocities that are higher than necessary in order to achieve full output (nominal output).

One of the methods is stall regulation of the rotor blades. This method turns the blades into the wind so that the angle of attack of the relative wind against the wing profile is increased and the rotor blades reach stall. That is to say that the wind gradually loses its lifting force in that the flows across the rotor blade go from being laminar to being turbulent. Thus, the excess energy is released.

The other regulating method is pitch regulation of the blades whereby the blades are turned in the opposite direction to that in stall regulation so that the wind is released by reducing the angle of attack of the relative wind against the wing profile. Thus, the lifting force of the rotor blade is reduced and less energy is recovered from the wind. This invention relates to this last regulating method which is called pitch regulation in this application.

In the case of large rotor diameters, there are liable to be large variations in the wind velocity across the rotor area both vertically and horizontally. This may cause greater fatigue problems of the blades than in the case of smaller plants if the individual thrust of the blades in the wind direction is not controlled and adjusted expediently. It may also result in large moments which try to turn the rotor out of the wind if the wind velocity at a given time is substantially greater on one half of the rotor (about the vertical axis) than on the opposite half. In prior art technology involving pitch regulation as described above, the rotor rpm for wind velocities above the nominal wind velocity will be regulated so that the rotor output which is equal to the rotor torque multiplied by the angular speed (rotational speed in radians) is kept as constantly equal to the nominal output of the wind power plant as possible. To achieve this, a control unit controls the pitch angle of the rotor

blades continuously. Output and rotor axial force are non-linear values as a function of variation of the wind velocity. When the wind velocity changes and the output from the rotor is kept constant by pitching the rotor blades, rotor axial force will change at the same time. The rotor axial force (thrust in the wind direction) may thus have large variations. These force variations cause major fatigue loads on the blades and tower structure, which in many cases can be dimensioning for these structural elements.

To illustrate this, we can look at the effect of pitch regulation in the prior art. If the momentary wind velocity is increased from the nominal wind velocity (e.g., 13 m/s) to twice that (26 m/s) whilst the output and the rotational speed of the rotor are kept constant, the pitch change of the blade will be about 20 degrees in order to prevent the rotor output from increasing at the higher wind velocity. The result of this pitch change of the blades is that the rotor axial force (thrust in the wind direction) is at the same time approximately halved, which causes fatigue loads on the blades and tower structure.

When weather conditions are such that there is, e.g., a 10 minute mean wind velocity of 19 m/s, such fluctuations in the wind velocity will typically occur accompanied by large variations in the total axial force of the blades and the rotor if the output is to be kept constant. Similar fluctuations in the axial force will occur for all average wind velocities above the nominal wind velocity to a greater or lesser extent if pitch regulation according to the prior art is used.

There will always be a certain delay between the aerodynamic momentary torque of the rotor and the generator torque. This is due primarily to forces of inertia of the rotor, drive gear and generator. Since pitch regulation according to the prior art makes use of measured values of rotational speeds or generator output, the pitch regulation will be inaccurate and delayed in relation to the momentary forces acting on the rotor, including the momentary rotor axial force. This means that for sudden decreases in the momentary wind velocity, the rotor blades will have an unduly large blade pitch angle and the rotor axial force may be drastically reduced or even negative. For the above example, in the case of a sudden decrease in wind velocity from 26 m/s to 13 m/s, and if the pitch regulation was not changed sufficiently quickly, this could result in a reduction of the momentary aerodynamic axial force of the rotor from 50% of the nominal axial force at 26 m/s wind to –30% of the nominal axial force at 13 m/s, i.e., in the opposite direction of the wind. Together, this means a change of 80% of the nominal rotor axial force. Such large fluctuations of the axial force because of the delayed pitch control will especially be a problem for the higher average wind velocities.

This will also mean that rotor blades dimensioned for a low annual average wind velocity could not be used for a location with high annual average wind velocity. Because of the increased fatigue loads that occur due to the large variations in the thrust of the blades in the wind direction, rotor blades intended for areas with high average wind velocities must be more robustly dimensioned. This may mean more costly and heavier blades. The fact that a location with high average wind velocity will have more operating hours will also increase the requirement of fatigue strength for the rotor blades.

For a floating wind power plant, the above-described effect that increased wind velocity reduces the rotor axial force because of the pitch regulation (for wind velocities above the nominal wind velocity) may also have negative effects on the motion pattern of the wind power plant. When the tower and rotor move into the wind, the relative wind velocity against the rotor will increase, which will result in a reduced rotor thrust because the pitch regulation tries to maintain constant output, which in turn will increase the movement of the tower against the wind. Conversely, when the tower and rotor move back in the same direction as the wind, the relative wind velocity against the rotor will decrease and, with the prior art, the blades will automatically be pitched (turned) to maintain nominal output to the generator. This in turn results in increased rotor thrust, which in its turn will increase the movement of the tower in the direction of the wind. The result of this is an extra excitation and intensification of the motions of the tower if prior art pitch regulation is used. This has been found to lead to large increases in fatigue loads for floating wind power towers.

Patent No. US-4201514 describes a method for regulating the pitch angle of the individual rotor blades in relation to variations of the wind velocity. The regulation describes how the torque of the individual blades about the rotor axis is automatically held constant in changing wind velocities. This has the same effect as for other prior art as described above. That is to say that the forces acting in the direction of the rotational direction of the blades, i.e., perpendicular to the wind direction, and which cause the blade to rotate, are held constant. A side effect of this is that the thrust of the blade in the wind direction will vary in the same way as described above for other prior art. Thus, this prior art will have the same effect on fatigue of the blades and tower because of varying thrust on the rotor blades when an attempt is made to hold the rotor torque constant.

The object of the invention is to overcome the disadvantages of the prior art.

In the method described below, the disadvantages of the prior art have been remedied or eliminated.

In one embodiment of the invention, a method is provided for controlling the output of a wind power plant comprising a converter unit, wherein when the output power of the converter unit is within a given range, the pitch angle of the rotor blades is changed with a view to minimising variations of the thrust of the rotor blades in the wind direction individually or collectively, and when the output power of the converter unit is outside this range, the pitch angle of the rotor blades is changed with a view to bringing the output power within the range.

In another embodiment of the invention, variations of the thrust of the rotor blades in the wind direction are minimised by regulating towards a calculated target value for the thrust of the rotor blades in the wind direction, the target value for the thrust in the wind direction being different for different average wind velocities.

In yet another embodiment of the invention, the target value for the thrust of the rotor blades in the wind direction is adjusted in relation to average converter unit output or rotor speed over a given period of time.

In still another embodiment of the invention, the target value for the thrust of the rotor blades in the wind direction is pre-defined and related to given average wind velocities.

In one embodiment of the invention, the thrust of the rotor blades in the wind direction is in addition adjusted by changing the rotor rpm by adjusting the generator rotation resistance moment and/or rotor brakes.

In yet another embodiment, the momentary thrust of the rotor blades in the wind direction is determined directly or indirectly by means of strain gauges, wind velocity measurements, by measuring geometric deflection of the blades, measuring the generator torque and/or measuring the generator output together with simultaneous measurement of the pitch angles of the blade or blades, and/or by measuring or using the pitch moment of the blades about the rotational axis of the pitch bearing either by mounting the blades leaning backwards in the pitch bearing, or by shaping the blades so that the impact point of the wind on the blade is behind the rotational axis of the pitch bearing in relation to the rotational direction of the rotor.

In one embodiment, the pitch angle of the rotor blades is in addition changed with a view to minimising direction errors for the wind power plant.

In one embodiment, the direction error is corrected if it is outside a given range.

In another embodiment of the invention, the pitch angle of the rotor blades is adjusted differently for different rotational positions.

In one embodiment, the pitch angles of the rotor blades are adjusted individually and/or independent of one another.

In one embodiment, the wind field in a plane substantially perpendicular to the wind direction is predicted by using directly or indirectly measured values of the wind forces acting on the rotor blade or blades that is/are at the front in relation to the rotational direction of the rotor.

In one embodiment, the thrust of the rotor blades in the wind direction is used actively to counteract motions of the wind power plant tower by regulating the pitch angles of the rotor blades.

In one embodiment of the invention, one or more anemometers/wind gauges are placed in a suitable location or locations on the wind power plant so that the spatial distribution of the wind velocity can be recorded and interpolations between the different anemometers can be made to form a picture of the distribution of the wind across the sweeping area of the rotor. This can be done by placing anemometers at substantially different heights and in substantially different horizontal positions. This spatial distribution of the momentary wind velocity can then be used to individually regulate the pitch of the rotor blades, optionally all the blades may be pitch-regulated collectively.

The wind field in a plane that is essentially perpendicular to the wind direction can be predicted by using directly or indirectly measured values of the wind forces which act on the rotor blade or blades which is/are at the front in relation to the rotational direction of rotor.

The rotor may advantageously be positioned downwind of the tower so that the anemometers record the wind velocity before it impinges on the rotor. In addition, directly or indirectly measured values of the thrust on the blade that is at the front in relation to the rotational direction of the rotor, of a given blade can be used to predict the wind field into which the given blade will move. In this way, the optimal pitch angle of the blades can be calculated in advance so that there is little or no delay between the aerodynamic forces and the pitch response of the rotor blades. Thus, sudden changes in the momentary wind velocity can be predicted. By using the horizontal distance between the upwind mounted anemometers and the vertical plane of the rotor and the wind velocity, the time delay from when the measurements are made until the actual wind velocity occurs in the rotor can be calculated. The controller unit that controls the pitch regulations is given access to all these measurements and can at any given time use this information to optimise the pitch angles of the blades. Thus, it is possible to avoid in particular the large rotor axial force reductions which occur in connection with sudden momentary

decreases in the momentary wind velocity because the prior art pitch regulation does not take place sufficiently quickly.

For momentary wind velocities above the nominal wind velocity of the wind power plant, the blades will initially be turned so that the axial force on the rotor is reduced. This is countered by increasing the rotational speed of the rotor by means of reduced or no pitch response whilst the generator torque optionally at the same time is reduced in accordance with input from the control unit which also will help to increase the rotational speed of the rotor. Both the rotor axial force and the output of the generator can then be held almost constant at optimal pitch angle within a small wind velocity increase. At a wind increase of about 10%, the rotational speed according to this method must be increased by about 10% to obtain both unchanged rotor axial force and unchanged output to the generator. The pitch angle must be changed at the same time. A similar method is used when there is a decrease in momentary wind velocity, but in that case the rotational speed of the rotor is reduced whilst the generator torque is, optionally simultaneously, increased in accordance with input from the control unit.

For larger changes in the momentary wind velocity, the following is done:
When there is a decrease in the momentary wind velocity compared to the average wind velocity measured over a longer period than the updating frequency of the pitch regulation, e.g., over a 10 minute period, the pitch angle of the blades will be changed less than when pure output-controlled pitch regulation is used. The result of this is that the rotor axial force remains unchanged, but that the output to the generator is slightly less than the nominal output. A 10% decrease in wind velocity gives a reduction in output of about 10% whilst the rotor axial force remains unchanged.

Similarly, for a 10% increase in wind velocity, a smaller change of the pitch angle of the blades will be effected than when pure output-controlled pitch regulation is used. The result of this is that the rotor axial force remains unchanged but the output to the generator is slightly greater than the nominal output. A 10% increase of the momentary wind velocity gives an increase in output power of about 10% whilst the rotor axial force remains unchanged. By combining the two outputs described above, the overall result will be that the momentary wind velocity can vary by typically +/- 20% without the rotor axial force varying. Since the attendant generator output variations will be short-term and will fluctuate around the rated power of the generator, the average generator output will be almost unchanged, i.e., equal to the nominal output (rated power), whilst the axial force for a given average wind velocity can be held constant or almost constant, typically within a +/-20% variation of the momentary wind velocity.

For a given average wind velocity, the rotor axial force (target value), which corresponds to the nominal output of the generator, can be calculated. Acceptable maximum and minimum values for the generator output variations around a mean value can be pre-programmed, and the pitch controller unit will then calculate optimal momentary pitch angles so that the rotor axial force is held as constant as possible around the said calculated target value whilst the generator output is maintained within the pre-programmed bandwidth.

The calculated target value for the rotor axial force will therefore vary with different average wind velocities. Within each average wind velocity, an attempt will then be made to keep the axial force almost constant using pitch regulation. The average wind velocity may, for example, be the mean of the last 10 minutes. Optionally, pre-calculated values may be used for the target values of the axial force for given average wind velocity intervals, e.g., divided into intervals of 0.1 m/s differences.

For momentary wind velocity variations in excess of about +/- 20%, pitch regulation can be carried out giving priority to not varying the generator output by more than the typical approximately +/- 10% as described above. On such large variations of the momentary wind velocity, the rotor axial force will start to vary, but also in these cases this variation will be substantially less than for pitch regulation according to the prior art.

Since an average value of the wind velocity over a longer period of time, e.g., a 10 minute average, varies much less than the momentary wind velocity variations, the described method will ensure that the rotor axial force variations will be considerably reduced, which will have a positive effect on the fatigue loads on the tower and rotor.

The same method as described above can also be used to actively regulate the rotor axial force in relation to a given mean value. If the rotor axial force in this way is actively controlled with varying value, this can be used, e.g., to apply forces to the tower in counter phase with its motions so that the motions of the tower are dampened.

The motions of the tower can, e.g., be recorded using an accelerometer.

Furthermore, the axial force can be used actively in a similar manner to counter any forces that try to turn the rotor out of the wind. This can be done by controlling the individual force of the rotor blades in the wind direction so that any torques that try to turn the rotor and/or the nacelle and/or the tower out of the wind are countered, reduced or eliminated by cyclically changing the individual pitch angle of the blades according to the physical position of each individual blade at any given

time, so that the axial force on the rotor is greater on one side or the other of the vertical axis of the rotor, as required. When a given rotor blade passes one side of the vertical axis of the tower, the pitch angle is increased, e.g., by 0.5 degrees, and when the same blade passes the opposite side, the pitch angle is decreased correspondingly. Therefore, this does not need to have any effect on the total rotor output or the total rotor axial force. The extra cyclic pitch variation is superposed only on the calculated pitch angle according to the above-described method in order to control the total rotor axial force. This described cyclic pitch regulation can also be used to actively control the rotor so that parts of, or optionally the whole of the wind power plant in the case of a floating plant, can be held in the desired position relative to the wind direction. Thus, it is possible to eliminate or reduce the size or number of motors which according to prior art turn the mill housing, or optionally the whole tower in the event the mill housing is non-rotatably mounted on the tower of a floating plant, in the desired position relative to the wind.

Furthermore, the thrust variations in the wind direction on each individual blade can be reduced by changing the pitch angle according to the above-described method in order to control the momentary thrust of the blade in the wind direction. The blade can then be controlled individually in relation to its position in its orbit and to measured values of the wind velocities in different positions in or around the sweeping area of the rotor.

The measured axial force will be recorded and included in the pitch controller unit for calculation of optimal pitch angle at any given time according to the described method.

Instead of just using measured wind velocity and pitch angle to calculate the rotor axial force, several other direct or indirect methods can be used.

Since the blades are mounted leaning backwards in the pitch bearing, i.e., the longitudinal axis of the blade deviates slightly from the pitch bearing shaft axis so that the longitudinal axis of the blades does not intersect the rotor rotational axis, and the pitch moment which then occurs can be measured via hydraulic pressure via the blade pitch control system and the axial force can then be calculated; or

By using strain gauges on the blades and/or on the main shaft of the rotor and/or on other parts of the wind power plant; or

Indirectly by measuring the pitch angles of the blade(s) and the rotor torque directly or by recording other parameters such as the generator torque, output etc. and then the corresponding rotor axial force can be calculated.

By measuring deflection of the blades using a mechanical or electronic measuring system.

Example of a preferred method

There now follows a description of a non-limiting example of a preferred method which is illustrated in the attached drawings, wherein:

Fig. 1 shows a floating wind power plant 1 with rotor 2 which may have a horizontally or substantially horizontally mounted rotor axis 11 mounted downwind of tower 4. The figure also shows mill housing 3, anemometers 5, anchor connection 6 and anchor 7.

Fig. 2 shows a wind power plant 1 located on land or in shallow water with rotor 2 which has a horizontally or substantially horizontally mounted rotor axis 11 mounted upwind of tower 4. The figure also shows mill housing 3 and anemometers 5.

Fig. 3 shows a wind power plant 1 that is located either on land or in shallow water or floating in water with rotor blades 13 which are rotatably mounted about their longitudinal axis or substantially about their longitudinal axis 14 with pitch bearings 10.

Fig. 4 is a flow diagram illustrating the method according to the invention.

Fig. 5 is a flow diagram for an optional part of the method according to the invention.

A wind power plant 1 with a horizontal or substantially horizontal rotor axis 11 consists of one or more rotor blades 1) which together form a rotor 2, where the rotor blades in a coordinated manner or individually can be turned (pitched) around their own longitudinal axis or essentially around their own longitudinal axis 14 primarily in order to control the rotor 2 output to the generator (not shown), and where the rotor shaft is secured in a mill housing 3 and the rotor shaft is connected to the generator optionally via a transmission system (gear). The pitch regulation of the rotor blades is carried out by a pitch control unit which on the basis of different recorded operational information, wind measurements etc. transmits a signal to the pitch motors indicating the amount of the required change in pitch angle at any given time.

The mill housing may be mounted on a tower 4 which is fixedly mounted on land 9 or on the seabed 8 or which is a part of a floating device or which itself constitutes a floating device with optionally one or more anchor connections 6 to an anchor 7

on the seabed 8. The design of the anchor system 6, 7 is of no importance for the described method.

One of the objects of the method described below is to reduce the variations of the rotor axial force compared with the prior art, whilst the resultant output to the generator is not significantly affected or is maintained within acceptable limits in relation to limitations of the drive gear, generator and power grid. It is also an object of the method to use the rotor axial force to actively counter the motions of a floating wind power plant. Furthermore, it is an object of the described method to control and counter rotational forces about the vertical axis 12 of the tower and to reduce the aerodynamic force variation on each individual blade through a whole rotation cycle resulting from different wind velocities at different levels (vertical wind shear) and in the horizontal direction parallel to the rotor plane (horizontal wind shear).

One or more anemometers 5 are placed in a suitable location or locations on the wind power plant 1 so that the spatial distribution of the wind velocity can advantageously be recorded and interpolations between the different anemometers can be made to form a picture of the distribution of the wind across the sweeping area of the rotor. This can be done by placing anemometers at substantially different levels and in substantially different horizontal positions. This spatial distribution of the momentary wind velocity can then be used to individually regulate the pitch of the rotor blades, optionally all the blades can be pitch-regulated collectively.

The rotor 2 may advantageously be positioned downwind of the tower 4 so that the anemometers record the wind velocity before it impinges on the rotor. In this way, the optimal pitch angle of the blades can be calculated in advance so that there is little or no delay between aerodynamic forces and the pitch response of the rotor blades. Thus, sudden changes of the momentary wind velocity can be predicted. By means of the horizontal distance between the upwind-mounted anemometers and the vertical plane of the rotor and the wind velocity, the time delay from when the measurements are made until the effect of the actual measured wind velocity occurs in the rotor can be calculated. The controller unit (not shown) that controls the pitch regulation is given access to all these measurements and can at any given time use this information to optimise the pitch angles of the blades 13. Thus, it is possible to avoid in particular the large rotor axial force reductions which occur on sudden momentary decreases in the momentary wind velocity because the prior art pitch regulation has a time delay.

In the cases where the average velocity is above the nominal wind velocity for the wind power plant 1 and the momentary wind velocity then increases beyond the

given average wind velocity, the rotational speed of the rotor 2 according to this method will be increased by means of reduced pitch response compared to the prior art, whilst the generator torque is, optionally simultaneously, reduced in accordance with input from the control unit, which will also help to increase the rotational speed of the rotor 2. Since the rotor axial force in general is increased on increased rpm for a given rotor output, the reduced rotor axial force resulting from the pitch turning of the blades in response to the increased momentary wind velocity can be compensated. The result is that within a small wind velocity increase, both the rotor axial force and the output of the generator can be held almost constant by increasing the rotational speed of the rotor and with optimal pitch angle. At wind increase of about 10%, the rotational speed must according to this method be increased by about 10% to obtain both unchanged rotor axial force and unchanged output to the generator. The pitch angle must be changed at the same time. A similar method is used when there is a decrease in momentary wind velocity, but in that case, the rotational speed of the rotor is decreased whilst the generator torque is, optionally simultaneously, increased in accordance with input from the control unit.

For larger changes in the momentary wind velocity the following is done:
When there is a decrease the momentary wind velocity compared to the average wind velocity measured over a longer period of time than the updating frequency of the pitch regulation, e.g., over a 10 minute period, the pitch angle of the blades is changed less than when pure output-controlled pitch regulation is used. The result of this is that the rotor axial force remains unchanged but the output to the generator is slightly less than the nominal output. A 10% decrease in wind velocity gives a reduction in output of about 10% whilst the rotor axial force remains unchanged.

Similarly, for a 10% increase in the momentary wind velocity, a smaller change of the pitch angle of the blades will be effected than when pure output-controlled pitch regulation is used. The result of this is that the rotor axial force remains unchanged but the output to the generator is slightly greater than the nominal output. A 10% increase in the momentary wind velocity gives an increase in output of about 10%, whilst the rotor axial force remains unchanged. By combining the two outputs described above, the overall result will be that the momentary wind velocity can vary by typically +/- 20% without the rotor axial force varying. Since the attendant generator output variations will be short-term and fluctuate around the nominal output of the wind power plant or the rated power of the generator, the average generator output will be almost unchanged, i.e., equal to the nominal output (rated power), whilst the axial force for a given average wind

velocity can be held constant or almost constant, typically within a +/-20% variation of the momentary wind velocity.

For a given average wind velocity and rotor rotational speed, the rotor axial force (target value), which corresponds to the nominal output of the generator, can be calculated. Acceptable maximum and minimum values for generator output variations around a mean value can be pre-programmed, and the pitch controller unit will then calculate optimal momentary pitch angles (in response to the momentary wind velocity) so that the rotor axial force is held as constant as possible around said calculated target value whilst the generator output is maintained within the pre-programmed bandwidth.

The calculated target value for rotor axial force will vary with different average wind velocities. Within each average wind velocity, an attempt will then be made to keep the axial force almost constant around this target value using pitch regulation. The average wind velocity may, for example, be the mean of the last 10 minutes. Optionally, pre-calculated values may be used for the target values of the axial force for given average wind velocity intervals, e.g., divided into intervals of 0.1 m/s differences.

For momentary wind velocity variations in excess of about +/- 20% as described above, pitch regulation can be carried out giving priority to not varying the generator output by more than the typical bandwidth of about +/- 10% as described. On such large variations of the momentary wind velocity, the rotor axial force will start to vary, but also in these cases this variation will be substantially less than for pitch regulation according to the prior art.

Since an average value of the wind velocity over a longer period of time, e.g., 10 minute mean, varies much less over time than the momentary wind velocity variations, the described method will ensure that the rotor axial force variations will be considerably reduced, which will have a positive effect on the fatigue loads on the tower and rotor.

The same method as described above can also be used to actively regulate the rotor axial force around a given mean value. If the rotor axial force is in this way actively controlled with varying value, this can be used, e.g., to apply forces to the tower 1 in counter phase with its motions so that the motions of the tower are dampened. This is particularly advantageous for floating wind power plants.

The control unit will in this case also have access to the motions of the tower. The motions of the tower can, e.g., be recorded using an accelerometer or other suitable measuring method.

Furthermore, the axial force can be used actively in a similar manner to counter any forces that try to turn the rotor out of the wind. This can be done by controlling the individual force of the rotor blades in the wind direction so that any torques that try to turn the rotor and/or the mill housing and/or the tower out of the wind are countered, reduced or eliminated by cyclically changing the individual pitch angle of the blades according to the physical position of each individual blade at any given time, so that the axial force on the rotor is greater on one side or the other of the vertical axis of the rotor as required. When a given rotor blade passes one side of the vertical axis of the tower, the pitch angle is increased, e.g., by 0.5 degrees, and when the same blade passes the opposite side, the pitch angles is decreased correspondingly. Therefore, this does not need to have any effect on the total rotor output or the total rotor axial force. The extra cyclic pitch variation is superposed on the calculated pitch angle according to the above-described method in order to control the total rotor axial force. This described cyclic pitch regulation can also be used to actively control the rotor 2 so that parts of, or optionally the whole of the wind power plant in the case of a floating plant, can be held in the desired position relative to the wind direction. Thus, it is possible to eliminate or reduce the size or number of motors which according to prior art turn the mill housing 3, or optionally the whole tower 5 in the event the mill housing is non-rotatably mounted on the tower of a floating plant, in the desired position relative to the wind.

Furthermore, the thrust variations in the flap direction (normally approximately the same as the wind direction) on each individual blade (which together constitute the rotor axial force) is reduced by changing the pitch angle according to the above-described method in order to control the momentary thrust of the blade in the wind direction. The blade can then be controlled individually in relation to its position in its orbit and to directly or indirectly measured values of the wind velocities in different positions in or around the sweeping area of the rotor.

The measured or calculated axial force will be recorded and included in the pitch controller unit for calculation of optimal pitch angle at any given time according to the described method.

Instead of just using measured wind velocity and pitch angle to calculate the rotor axial force, several other direct or indirect methods can be used.

Since the blades 13 are mounted leaning backwards in the pitch bearing 10, i.e., the longitudinal axis 14 of the blade deviates slightly from the pitch bearing shaft axis so that the longitudinal axis 14 of the blades does not intersect the rotor rotational axis 11 and the pitch moment which then occurs can be measured via hydraulic

pressure via the blade pitch control system, and the rotor blade thrust in the wind direction for each individual blade can then be calculated; or

By using strain gauges on the blades 13 and/or on the main shaft of the rotor and/or on other parts of the wind power plant; or

Indirectly by measuring the pitch angles of the blade(s) 13 and the rotor 2 torque directly or by recording other parameters such as the generator torque, output etc. and then the corresponding rotor axial force of the rotor can be calculated.

By measuring deflection of the blades using a mechanical or electronic measuring system.

An embodiment of the method according to the invention is illustrated in Fig. 4 by means of a flow chart. The method is based on the determination in 40 of whether an instantaneous/momentary rotor speed, or optionally output power of the generator is within a range of the nominal value for the wind power plant, in the example, by determining whether the rotor speed or optionally the output power of the generator is within +/- 10% of the nominal value.

If the instantaneous/momentary rotor speed, optionally the output power of the generator, is within the range, an attempt will be made to minimise the rotor axial force variations, optionally the thrust of each blade in the wind direction individually, by regulating towards a target value for the axial force. In 44 it is then determined whether average rotor speed or average generator output power for a given time t, e.g., the last 10 minutes, is above or below the nominal output of the wind power plant. According to this, the target value for the rotor axial force is adjusted in 45, 46. As previously described, a new target value for the axial force can be calculated on the basis of the mean value of the axial force over a given period of time t, for example, of 10 minutes with a given incremental increase or reduction of the target value for axial force depending upon whether it is desired to increase or decrease the average output of the generator. The target value for the rotor axial force may also optionally be a pre-calculated value related to the average wind velocity. The instantaneous value of the rotor axial force is then compared in 47 with the target value for the axial force as achieved in 45/46 and the rotor blade pitch angle is then changed in 48 and 49 in accordance with this comparison.

If, on the other hand, the instantaneous/momentary rotor speed, or optionally the output power of the generator, as calculated in 40 is outside the given range, an attempt is made to come within this range by adjusting the pitch angle in the same way as in the prior art in order to bring the rotor speed, or optionally the average output power of the generator within the desired range, e.g., within +/-10% of the

nominal. The pitch angle is adjusted in 42/43 according to the calculation in 41 of whether instantaneous/momentary rotor speed, or optionally output power of the generator, is above or below the desired range. In this way, the pitch angle is adjusted primarily with a view to maintaining a constant rotor axial force regulated towards a slow-varying target value, and unlike the prior art, the pitch angle will only be adjusted to the extent necessary to bring generator output power or rotor speed within the desired range. Thus, there will be a smaller adjustment and smaller rotor axial force variations than with the prior art when regulation is effected towards a constant value for the generator output with attendant large rotor axial force variations.

In the example in Fig. 4, the pitch angle of the rotor blades can be adjusted either for all the rotor blades collectively, or for each individual rotor blade. For systems where it is possible to adjust each individual rotor blade, directional information for the wind power plant can be taken into account, in addition to the aforementioned moments, with a view to holding the wind power plant in a stable position. This information 50 is taken into account in step 47 in the figure. Figure 5 illustrates in more detail the steps for providing this directional information.

In step 51 sinus(α) is calculated or recorded, where α is the rotational position of the blade, i.e., it describes where in the rotation each individual rotor blade is. In step 52 it is decided whether the direction error of the wind power plant direction relative to the wind direction is outside a given range, in this case +/-5°. If the direction error is within the range, no action is taken, but if the direction error is outside the range, a rotational mechanism for the tower is optionally triggered and a signal is calculated in 55, 56 according to which side of the range the direction error is on. The information provided in 55 or 56 is superposed on the control signals provided to adjust the pitch angle with respect to the rotor axial force variations, optionally the thrust of each individual blade in the wind direction. The direction error information comprises information about rotational position, i.e., the pitch angle is adjusted individually for each blade according to its momentary rotational position. This means that the thrust of each individual blade in the wind direction is adjusted differently for the different rotational positions so that a force effect is obtained that counters the direction error for the wind power plant.